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IONIZING RADIATION AND FOOD PRESERVATION

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The methods of using ionizing electromagnetic radiation to preserve food are reviewed. Pasteurization, sterilization, and disinfestation are the most important applications. Using radiation for these purposes can be more effective than conventional processes, and if applied on a large scale, should also be economically competitive.

INTRODUCTION

Over the last few decades, the preservation of food with electromagnetic radiation has reached the point of commercial application. By exposing foods to X-rays, gamma-rays, and electron beams, a wide variety of disease and spoilage producing organisms can be overcome. Improvements in nutrition, flavor, and texture can be had over conventional freezing and canning. Costs are uncertain, but will probably be competitive for large volume applications. There is little doubt that these technologies will become economically important if questions to do with consumer acceptance and regulatory control are resolved.

SUMMARY

This review indicates the numerous ways in which ionizing radiation may be used to preserve food. Of these, the most important are, pasteurization, sterilization, and disinfestation. Irradiation preservation can yield foods which are more wholesome and better tasting than many conventional processes. Extensive research has not revealed any significant health hazards, and this is indicated by increased regulatory approval.

The cost of using ionizing radiation to process foods is dominated by the capital expenditure required to construct irradiation facilities. Application will probably be limited to foods where large volumes may be processed to achieve economies of scale. As facility size increases, accelerators become more economically attractive than radionuclide sources. Specific costs are still highly uncertain.

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THE PRESERVATIVE EFFECTS OF IONIZING RADIATION

The main area of interest in electromagnetic preservation involves exposing food to X-rays, gamma-rays, and electron beams. These forms of radiation are energetic enough to ionize food molecules and initiate a wide range of electrochemical changes. All three types of radiation produce very similar effects. They may be used to pasteurize, sterilize, disinfest, inhibit sprouting, or delay ripening. These different processes will each be discussed in turn. Other forms of electromagnetic radiation may be used to preserve food, and these are briefly discussed in the appendix.

Predictions are that the most likely application for radiative food processing will be to extend the shelf-life of foods through pasteurization/1,2/. This is known as radurization (light pasteurization) or radicidation (extensive pasteurization). Doses are typically less than 1 Mrad. (See glossary for explanation of units.)

Radiation pasteurization yields products similar to the familiar products that have been treated using heat, and some refrigeration is generally required. However, radiation pasteurization has a major advantage over conventional pasteurization because there is only a slight temperature rise in the food during treatment. This makes it easier to preserve the flavor, odor, color, texture and nutritional value of fresh foods. Other advantages include dry packing, no loss of natural juices, larger container sizes, and the possibility of treating completely new products/1/. For example, whole turkeys may be treated to control Salmonella, or spices may be pasteurized without losing their aromatic qualities. Treated seafood may be kept unfrozen and therefore be available in 'fresh' condition further from the coasts.

Sterilization using radiation is a second important process. It is known as radappertization/3/. Typically the product is blanched to inactivate spoilage producing enzymes, then sealed and frozen in a package free of oxygen. These last two steps limit the formation of undesirable chemical by-products during subsequent irradiation. Spoilage and disease organisms are killed with radiation doses of 1-5 Mrad. After exposure, such products may be stored for years without refrigeration.

The quality of the food preserved in this way is superior to conventional processes using high temperature canning. Textures and flavors are well maintained. Space shuttle astronauts use food supplies preserved in this way, although more conventional military rations are the primary market. Medical patients who require completely sterile conditions also use these products.

Disinfestation is another important process which may use ionizing radiation/4/. It is typically used to control beetles or moths in grains and dried fruits. In any case there are two main techniques involved. The most direct is to simply kill all insects using radiation doses of about 500 krad. The second approach is to expose the foodstuffs to about one tenth this dose which produces sexual sterility followed by disinfestation in one generation. Both techniques can be very effective and may produce more complete disinfestation than conventional fumigation. The problem of insects developing a resistance to available insecticides is overcome, and there is no risk of chemical poisoning from residual fumigants.

Ionizing radiation may also be used to inhibit sprouting in potatoes, onions and garlic during storage. This is done by killing the plant embryo with exposures of about 10 krad. The technique of applying this to potatoes was pioneered in Canada and is now widely accepted throughout the world/5/. The advantages of extended shelf life without refrigeration are somewhat offset by damage resulting from additional handling.

As a last application, it has been found that exposure to ionizing radiation may delay the onset of ripening in some fruits/6/. This effect is pronounced in bananas, mangoes and papayas but has not received very much attention. The prospects for application look quite limited.

METHODS OF PRODUCING IONIZING RADIATION

The three general types of ionizing radiation used for food preservation are X-rays, gamma-rays and electron beams. The means of producing these radiations are quite distinct.

Most work in food preservation has been done with gamma-rays produced in the radioactive decay of Co^{60}. This radionuclide is obtained from nuclear reactor control rods, and Ontario Hydro is a major supplier. The radiation produced is diffuse and capable of penetrating metres into the food product/7/. Because the source cannot be aimed or turned off, extensive shielding is required.

Electron beams are produced by a variety of electrically powered machines generically termed accelerators. They produce intense, high power beams which may be steered, focused, pulsed and turned completely off. The internationally approved safety limit on beam powers is 10 MeV. This limits the penetration of the radiation to about 3 or 4 cm.

X-rays are also produced in accelerators as a secondary product of electron beams. They may be pulsed and directed, but are more expensive to produce. Penetration depths are several tens of cm, and may be adjusted by filtering.

COSTS

Since food irradiation facilities are still largely experimental, cost projections are highly uncertain. However there is broad agreement on the following points. First, it is clear that irradiation processing will be capital intensive, but that operating costs should be quite low/8/. Because of this, there should be important economies of scale/9/. It is estimated that an economically efficient facility should be able to process about 100 Mrad tons per day of operation/10/. Also, it is generally agreed that accelerators become more cost effective than radionuclide sources as the size of the facility increases. A crossover point of about 20-40 kW (2-4 MCi) has been estimated/7/.

As for specific dollar costs, one 1980 estimate/8/ priced the average food irradiation facility at $3-7 million. Processing cost estimates were $1.50 per ton of disinfested grain, and $0.06 per kg of pasteurized poultry. Further clearly worked-out examples of cost estimates are available/11/, however these estimates are very uncertain. For example, it has been pointed out/12/ that one risk factor (which most estimates ignore) is simply that the weather will cause completely unpredictable changes in the demand for irradiation capacity. Therefore, any rational investor will demand a premium for, and so increase the cost of, operating such a facility.

NON-TECHNICAL FACTORS

Obviously, a major barrier impeding application of this technology is consumer acceptance. Food irradiation has unfortunately become confused with nuclear power, nuclear fallout, and nuclear weapons. These associations seem spurious.

There are however legitimate concerns about the safety and wholesomeness of the treated foods. These questions have been assiduously investigated over the last twenty years, and no significant

health hazards have been detected. This fact is reflected in growing regulatory acceptance. Since 1980, irradiative processes have been approved for eighty different foods in twenty-five countries/8/.

It should be noted that conventional food preservation techniques are far from being perfectly safe. There are a wide variety of health risks from chemical preservatives and residual fumigants. In addition there are frequent outbreaks of Salmonella and other types of food poisoning which arise from the ineffectiveness of conventional processing.

Another non-technical factor influencing radiation food processing is government regulation. In Canada, the radiation process is classified as a "food additive" and the sorts of foods that can be treated are determined by the Federal Department of Health and Welfare. Irradiated foods have yet to be seen in Canadian supermarkets, and there are no Canadian food processing companies who use this technology. In 1985 a construction license for an accelerator was issued to Qix Corp. of Richmond, BC, who planned to use an accelerator for food irradiation, however the company is not presently in business/17/.

POSSIBLE INVOLVEMENT FOR THE UTILIZATION SECTION

Due to the high cost of accelerators and radionuclide facilities, the development of a demonstration capacity seems out of the question. However some small accelerators in the half to one million dollar price range are now becoming available/17/. As prices drop, the factors constraining application will change, and some effort should probably be spent on keeping up with these new developments.

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APPENDIX: LOW ENERGY RADIATION

The use of electromagnetic radiation for the preservation of food is not confined to the ionizing parts of the spectrum. Some of the simplest examples of the use of electromagnetism for food preservation involve the direct substitution of electroheat in conventional cooking, freeze-drying, fermentation and packaging processes. There are many examples of the use of infrared, radio-frequency and microwave energy to provide straightforward heating. Advantages over conventional methods include deep, quick and energy efficient heating.

A novel use of microwaves for food preservation is the control of insects in stored grains/13/. A three second exposure to 39 MHz radiation produces 100% mortality of rice weevils in red winter wheat due to selective heating of the insects. However, costs are several times conventional fumigation.

At much higher frequencies, ultraviolet radiation has been used to retard bacterial growth on food surfaces and in clear liquids. Positive results have been demonstrated for extending the storage life of refrigerated mutton/14/, and apple cider/15/ using simple UV lamps. Even the ultraviolet component of sunlight may be used to sterilize maple sap as it is collected in transparent plastic tubes for the manufacture of maple syrup/16/.

GLOSSARY

Beta particle - A high-speed electron ejected from an atomic nucleus in certain types of radioactive disintegrations.

Curie (Ci) - The unit of radioactivity. A Curie is defined as that amount of radioactivity which involves the disintegration of 3.7 $X10^{10}$ atomic nuclei in 1 sec.

Electron Volt (eV) - The unit of energy equivalent to the amount of energy gained by an electron when accelerated by a potential of one volt.

Gamma radiation - Electromagnetic radiation of a very short wavelength produced by the spontaneous disintegration of the atomic nucleus.

Gray (Gy) - The unit of energy absorbed from ionizing radiation by the matter through which the radiation passes. A radiation dose of 1 Gy involves the absorption of 1 J of energy by each kilogram of matter through which the radiation passes. The Gy is an SI unit and is equivalent to 100 rad.

Rad - The unit of energy absorbed from ionizing radiation by the matter through which the radiation passes. A radiation dose of one rad involves the liberation of 100 erg of energy into each gram of matter through which the radiation passes. One Mrad corresponds to the amount energy required to raise a kilogram of water by about 2.4 °C. Although commonly used, the rad is not an SI unit and is being superseded by the Gray. One Gy is equivalent to 100 rad.

Radappertization - Exposure to ionizing radiation of food in hermetically sealed packaging at doses necessary to kill all organisms of food spoilage or public health significance. Doses used are greater than one Mrad. Analogous to thermal sterilization (canning).

Radicidation - Exposure of food to ionizing radiation at doses necessary to kill all nonspore-forming pathogens. Doses used are generally below one Mrad. Analogous to pasteurization.

Radurization - Exposure of food to ionizing radiation to reduce population of organisms in order to delay onset of spoilage. Doses are generally below one Mrad. Analogous to pasteurization.

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